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Study of α cluster structure in ^{22}Mg

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Summary. — The α-cluster structure in the nuclei has been investigated for the perspective of nuclear structure. Contrary to the case of the $4N$ nuclei with $N = Z$, the experimental evidences of the clustering structures for the proton-rich systems are still lacking information. In order to study the interesting proton-rich ^{22}Mg radionuclide, the ^{18}Ne(α,α)^{18}Ne elastic scattering will be measured at the Center for Nuclear Study Radioactive Ion Beam Separator of the University of Tokyo. By comparing the experimentally-obtained excitation function with theoretical R-matrix calculations, the resonance parameters of the ^{18}Ne+α system will be provided in the energy range $\sim 1\,\text{MeV} < E_{c.m.} < 12.4\,\text{MeV}$.

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1. – Introduction

The study of α-cluster structure has been one of the most interesting topics from the earliest days of nuclear physics. The α-cluster structure has been relatively well studied for self-conjugate $4N$ nuclei such as ^{8}Be, ^{12}C, ^{16}O, and ^{20}Ne [1-3]. In these nuclei, energy levels with large α reduced widths were found to form the rotational bands, which showed a molecular structure of cluster levels clearly. In recent years, the studies on α-cluster were extended to the neutron-rich nuclei with the help of new theoretical models and rare isotope beams. Recent works on $N > Z$ nuclei reported the evidences of α clusterings in ^{10}Be, ^{12}Be, ^{16}C and ^{22}Ne [4-9]. Experimental data for α-cluster structure of radioactive nuclides are still rare especially for proton-rich nuclei.

The theoretical study of the level structure of proton-rich ^{22}Mg (^{18}Ne + α) system was investigated by M. Dufour and P. Descouvemont with the Generator Coordinate Method (GCM) calculation [10, 11]. Remarkably, doubling cluster states around $E_x =$ 12 or 13 MeV were expected, which is similar to its mirror nucleus, ^{22}Ne case. Relatively large reduced α widths indicate that those levels could be populated through the α elastic scatterings on ^{18}Ne. Considering the fact that the level density of proton-rich nucleus is generally lower than that of neutron rich nucleus, one might expect that observing the doubling states in ^{22}Mg is easier than the case of ^{22}Ne. It was shown, however, that the excitation function of the ^{18}Ne + α elastic scattering is rather featureless contrary to the ^{18}O + α elastic scattering case [9]. Possibly, this might indicate the levels are actually located outside of the energy range that was measured in ref. [9], which is $10\,\mathrm{MeV} < E_x < 14\,\mathrm{MeV}$.

Moreover, as pointed out by Kimura in ref. [8], the hybrid GCM for the molecular bands predicts new singlet states having negative parities in the energy range $E_x =$ 14.8–22.5 MeV in ^{22}Ne. By considering the similarities in the level structures between two mirror nuclei, it can be seen that ^{22}Mg nucleus also has those of singlet states with negative parities. Then, searching for the expected energy levels in ^{22}Mg in the relatively high energy region $E_x =$ 14–20 MeV can provide useful information regarding the α-clustering structure of the nucleus.

In this work, we propose the ^{18}Ne(α, α)^{18}Ne experiment in order to identify the α-cluster structure of ^{22}Mg in the energy region $E_x =$ 8.6–20 MeV ($E_{c.m.} =$ 1–12.4 MeV). By performing this experiment, resonance parameters such as spins, parities, and α widths of excited states in ^{22}Mg will be investigated.

2. – Experimental method

The ^{18}Ne(α, α)^{18}Ne scattering was measured at the Center for Nuclear Study Radioactive Ion Beam Separator (CRIB) at RIKEN in September 2016. By adopting the thick target method, a large energy range of the ^{18}Ne + α system (^{22}Mg) can be investigated in a single run.

The radioactive ^{18}Ne beam was produced by in-flight method through the ^{3}He(^{16}O, n)^{18}Ne reaction. The primary ^{16}O (7.4 MeV/u) beam from the AVF cyclotron will impinge on the 360 Torr of the ^{3}He gas target. The target chamber will be cooled down to $\sim$ 90 K by using the cryogenic system to make the gas target density higher [12].

Assuming a cross section of $\sim$2 mb/Sr for the ^{3}He(^{16}O, n)^{18}Ne reaction [13], a target thickness of 1.54 μg/cm^2, a primary beam intensity of 600 pnA, and a CRIB Wien filter transmission efficiency of 30%, $\sim 6\times10^5$ particles per second (pps) of ^{18}Ne beam intensity

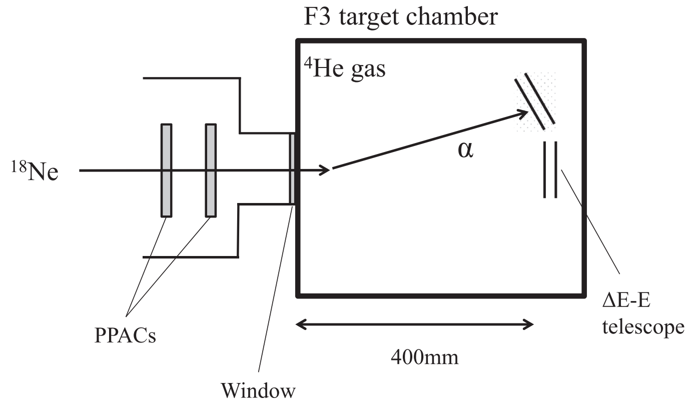

Fig. 1. – The schematic experimental setup is shown. A 3.6 MeV/u ^{18}Ne beam was bombarded on the ^{4}He gas target. Scattered α particles were detected by silicon detector telescopes. Two PPACs located just before the target chamber provide beam current and position information.

can be achieved at the reaction target chamber F3. The ^{18}Ne beam has already been produced by using this method before [14] at CRIB.

The experimental setup is shown schematically in fig. 1. Two Parallel Plate Avalanche Counters (PPACs) [15] are located just upstream of the target chamber for the beam current and position monitoring. The reaction target chamber at F3 was filled with ^{4}He gas at 760 Torr. Since the ^{18}Ne beam particles was fully stopped in the gas just before they get to the detector array which is located at 400 mm downstream from the entrance window, the ^{4}He gas molecules act as a thick target.

Recoiling α particles were detected by two ΔE-E telescopes located in the gas target chamber. Each telescope was configured with two layers of 16-strip silicon detectors with thicknesses of 20 μm(ΔE) and 1500 μm(E). In this configuration, the energy levels of ^{22}Mg located at $E_x \gtrsim 8.6\,\mathrm{MeV}$ are expected to be populated.

Although the (α,α) elastic channel would be most dominant, events from possible (α,α') inelastic channels might be present. In order to separate the elastic events from inelastic ones, a peak shift method was used, which was proven to be very useful in previous ^{22}Mg + p scattering measurements performed at CRIB [16].

3. – Anticipated results

The excitation function of the ^{18}Ne + α system will be extracted from the thick target measurement. The experimentally-obtained excitation function will be compared with theoretical R-matrix calculations by using a R-matrix code, SAMMY [17, 18]. Figure 2 shows the estimated cross section calculated using SAMMY. Resonance parameters are adopted from previous works [9, 19, 20]. Since the excitation function of the ^{18}Ne(α, α)^{18}Ne reaction has not been measured at the energies above $E_x = 14\,\mathrm{MeV}$, we expect to provide the first experimental result on the excitation function. If any resonance is found in the energy range, the resonance parameters will be deduced through the R-matrix analysis and the α-cluster structure information will be extracted.

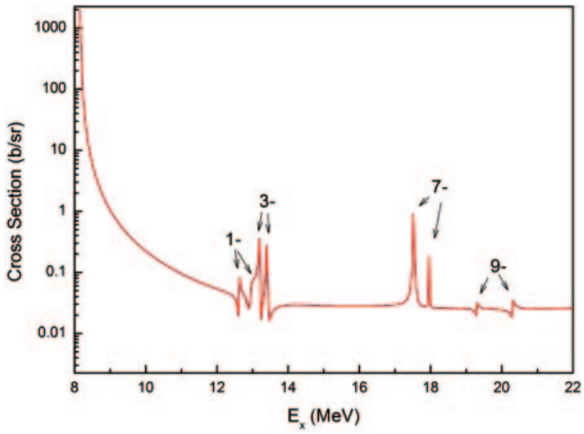

Fig. 2. – Cross section estimated by the R-matrix code, SAMMY. The resonance parameters were adopted from previous works [9, 19, 20].

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